CURRENT CONCEPTS REVIEW

Selective Thoracolumbar/Lumbar Fusion in Adolescent Idiopathic Scoliosis: A Comprehensive Review of the Literature

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Abstract

In Adolescent Idiopathic Scoliosis (AIS), correction surgery can correct the maximum movement and balance of the spine. Under certain conditions for two simultaneous curvatures, the procedure, in which correcting one of the curvatures can result in the automatic correction of another curvature, is called selective fusion, attracting spine surgeons' interest because of more movement in the spine. However, the majority of surgeons have not used this technique due to the lack of sufficient information. The current study aimed to totally investigate selective thoracolumbar/lumbar fusion and to provide accurate information on outcomes and complications of surgery for spinal surgeons. This technique can also help spinal surgeons have a better selection of patients' surgical procedures.

Level of evidence: IV

Keywords: Adolescent idiopathic scoliosis, Selective fusion, Thoracolumbar/Lumbar

Introduction

Adolescent Idiopathic Scoliosis (AIS) is considered a three-dimensional spine deformity, leading to disability and different physical and psychological problems. Proper preoperative treatment is needed to help the patient improve appearance while maintaining the function of the spine as much as possible.

Some researchers have used classification systems, such as King and Lenke, to standardize surgical treatment.[1, 2] However, the King classification is easy to use, it just considers the thoracic curve and evaluates the curve solely on the coronal plane. Moreover, Lenke classifies the thoracolumbar and lumbar curves and evaluates the deformity on the sagittal plane, without any consideration of vertebral rotation.

The determination of fusion levels is considered one of the most challenging issues in the treatment of AIS. However, the principles of fusion, published by Moe et al., [3] have mostly remained without any significant changes, some changes are needed due to the advancement of instrumentation systems. The corrective surgery in AIS aimed to have an optimally corrected and well-balanced spine, prevent curve progression, and provide maximum spine motion. Consequently, Selective Fusion (SF), in which only structural curves are addressed, and nonstructural curves are waived to preserve the spine's mobility, has attracted spine surgeons' interest recently.[4,5] In 1983, King et al.[2] introduced SF about Selective Thoracic Fusion (STF) in King type 2 AIS. In addition, the SF is defined in adolescents, who have a curvature in the thoracic and thoracolumbar or Lumbar (TL/L) spine, and fusion only is performed for one curve. Therefore, another curve is expected to spontaneously improve. No clear benefits have been recently presented about this method. However, some surgeons believed that complete fusion can lead to greater spinal strength, less failure, and better treatment outcomes, the others, who do SF, due to increasing mobility in the spine think that patients can achieve a higher level of activity and benefit from the quality of life after surgery.[6-8] It is crucial that TL spine fusion does not lead to the same amount of motion loss as extending a fusion from the thoracic to the lumbar spine. Therefore, the selection of TL/L fusion requires careful evaluation for maximum radiographic and clinical improvement and minimum complications. Furthermore, the selection of the patient and the vertebrae placed in the fusion is considered the most challenging in selective TL/L fusion.

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Criteria for selective TL/L fusion

In 2001, Lenke's classification for AIS was performed based on the implication of selective or non-selective fusion in treatment.[1] According to this technique, only structural curves should be considered in the fusion, leading to excluding nonstructural curves from the fusion plan. The selective TL/L fusion was defined for Lenke type 5C and 6C.[9] Based on Lenke's classification, the curve pattern is classified as Lenke 5C or 6C when the size of the TL/L curve exceeds the thoracic curve.[1] Further, there is no challenge regarding selective fusion in Lenke Type 5 curve since the value of the Cobb angle and T10-L2 kyphosis decrease to less than 25 and 20 degrees, respectively, in the thoracic curve on the side bending X-ray. The thoracic curve without these features (Lenke Type 6) can make problems, although selective TL/L fusion is still possible in some situations. It seems that selective TL/L fusion should be applied only when the thoracic curve is flexible, and the patient is close to the end of maturity.[10] Otherwise, the thoracic curve continues, leading to adverse effects on the distal or proximal instrumentation segments. Based on the obtained experience, selective TL/L fusion in premenarchal girls can cause a higher risk of surgical failure.

Dwyer and Schafer performed the selective TL/L fusion[11] and believed that the lumbar curve alone needs fusing when the entire correction of the thoracic curve on the side bending radiographs. In 1988, the first criteria for selective TL/L fusion were defined by Ogilvie,[12] which was the minor compensatory Main Thoracic (MT) curve <40°, enough flexibility, and no cosmetic deformity.

Deviren et al.[13] also showed that curve magnitude and patient age are the main predictors of curve flexibility. Larger curves and older patients demonstrate less flexibility of the structural curve. Huitema et al.[14] also released that the relative (%) correction of the TL/L curve decreased with increasing age. Majd et al.[15] also showed that the correction of less than 50 % of the original curve or less than 40º can lead to including the compensatory thoracic curve in the fusion.

Lenke et al.[16] published the radiographic criteria for satisfactory anterior selective TL/L fusion, which were TL/L: MT Cobb ratio, Apical Vertebral Translation (AVT), and Apical Vertebral Rotation (AVR) more than 1.25, MT curve flexibility more than TL/L curve (ideally MT side bending Cobb angle less than 25º), and lack of TL junctional kyphosis (T10-L2<20º). They also showed some clinical criteria for left TL/L curves, including shoulders' level or left shoulder high, TL/L trunk shifts more than MT trunk shift, TL/L scoliometer measurement more than MT scoliometer measurement by 1.2 ratios, and Thoracic rib prominence acceptable to the patient, parent, and surgeon preoperatively because thoracic rib cage undergoes minimal change postoperatively.

Finally, Sanders et al.[17] assessed the necessary criteria for successful anterior selective TL/L fusion and concluded, after a two-year follow-up of 49 patients who had undergone selective anterior TL/L fusion, that a thoracic curve of fewer than 40 degrees can obtain acceptable results. According to the triradiate cartilage, the best predictor of the favored outcome was skeletal maturity. Furthermore, TL/L to thoracic Cobb ratio of greater than 1.25, TL/L curve ≤ 55°, and/or a thoracic curve side-bending Cobb measurement of 25° or less were predictors of a satisfactory outcome. It seems that all the criteria about the anterior selective TL/L fusion also apply to the posterior procedure. The criteria for selective TL/L fusion are shown in [Table 1].

Table 1: criteria for selective TL/L fusion

Category	Criteria	Remarks
Candidate	Lenke 5C, 6C	
Clinical criteria	Shoulders level or left shoulder high	For left TL/L curves
	TL/L trunk shift >MT trunk shift	
	TL/L scoliometer measurement >MT scoliometer measurement by 1.2 ratio	
	Thoracic rib prominence acceptable to patient, parent, and surgeon preoperatively	
Radiological criteria	$\frac{\text{AVT thoracolumbar/lumbar}}{\text{AVT main thoracic}} > 1.25$	Possible if AVT criteria only Better if 2 or 3 criteria met
	$\frac{\text{AVR thoracolumbar/lumbar}}{\text{AVR main thoracic}} > 1.25$	
	$\frac{\text{thoracolumbar/lumbar } Cobb angle}{\text{main thoracic } Cobb\ angle} > 1.25$	
	MT curve flexibility more than TL/L curve ideally MT side bending Cobb (angle<25º)	If >25º Selective fusion possible if other criteria met
	lack of TL junctional kyphosis	T10-L2<20º
	Lenke's sagittal modifer N	T5-T12 kyphosis= 10-40 º
Skeletal maturity	Triradiate cartilage closed	
	postmenarchal girls	
Additional criteria	MT curve ≤ 40º	If >55º Selective fusion possible if other criteria met
	TL/L curve ≤ 55°	

MT: main thoracic, TL/L: thoracolumbar/lumbar, AVT: apical vertebral translation, AVR: apical vertebral rotation

Anterior or posterior approaches

Selective TL/L fusion can be performed from either the anterior or posterior approaches. Anterior correction and fusion with solid rod instrumentation have several superiorities compared to that of the posterior approach, as follows: 1) the corrective force is applied at the greatest space from the center of the curve in both lateral displacement and rotation, leading to more substantial correction power [15,18,19,2] the spine is shortened in anterior, unlike the posterior procedure, resulting in reducing the risk of a traction injury to the spinal cord [18,3] more mobile segments can be saved due to shorter fusion levels,[20,21,4] crankshaft phenomenon in children is prevented [18] with better visualization and inter-body fusion and less dependency on technique.[22-24] More vertebral rotational correction and less adjacent segment disease are also reported as advantages of this procedure.[25] The complications included instrumentation failure, pseudarthrosis, pulmonary impairment, disability to extend fusion level, and a kyphogenic compression mechanism.[25-27] However, only 23 study groups (38%) have conducted anterior procedures due to surgeons' information on a posterior approach.[28] Also, a better correction can be achieved with fewer disadvantages of the posterior approach with the advent of pedicle screws, increasing the strength of the spinal device structure.

The mean correction rate of 70-85% of fused TL/L curve is reported in anterior or posterior approaches in Lenke type 5C.[14, 29, 30] Also, a 40-55% correction rate for unfused MT curves with 1 to 10 degrees correction loss is reported regarding fused or unfused curves at the final follow-up. However, the coronal and shoulder imbalance immediately after surgery was up to 50%, most of them gained their balance during the follow-up.[31,32] Although preoperative L5 tilt more than 10° on bending radiographs, larger Lowest Instrumented Vertebra (LIV) – Lower end Vertebra (LEV), younger age at surgery, larger TL/L curve, and thoracolumbar/lumbar AVT at the one week after surgery, TL/L curve with less flexibility, more TL kyphosis, greater distal junctional angle, preoperative LIV tilt >25° and failure to restore the LIV tilt to <8° and preoperative UIV translation ≥25mm all have been reported as a risk factor for postoperative Coronal Imbalance (CIB).[31-35] Despite many studies on the factors affecting postoperative CIB, most patients with postoperative CIB and shoulder imbalance have coronal and shoulder balance at the end of the follow-up period.[31,32,34] In addition, CIB does not affect patients' back pain and clinical outcome at least in short-term follow-ups.[32,36,37]

Comparing the anterior and posterior approaches showed that the correction rate was similar in the fused TL\L curve, unfused thoracic curve, and complications.[24, 38] On the other hand, a lower incidence of instrument failure and pseudoarthrosis and a higher incidence of Proximal Junctional Kyphosis (PJK) are reported due to the structural rigidity and longer fusion levels in the posterior procedure.[28,39,40] Even a less-fusion level can maintain more movement in this region since most of the movement of the spine is in the lumbar region. Li et al.[40] showed that posterior TL/L fusion is superior in the restoration of Lumbar Lordosis (LL) and the maintenance of lordosis in instrumented segments compared with the anterior procedure from short- to long-term postoperative follow-up in the sagittal plane. They also showed that even new-generation instrumentation with structural cages in the anterior procedure could not prevent the potential kyphosis of instrumented segmental angle in the long term. Furthermore, they reported that Thoracic Kyphosis (TK) was well restored in both groups. However, the TK in the posterior group was higher at the final follow-up, the difference was not statistically significant. These results were consistent with those of a meta-analysis study.[38]

Selective TL/L fusion in Lenke type 6

Few studies are conducted on the outcome of unfused structural thoracic curves following selective TL/L fusion in Lenke 6C AIS patients. Chang et al.[41] compared the radiographic parameters of 18 Lenke type 5C AIS patients with 13 Lenke type 6C with a mean correction rate of 32.2% following posterior selective TL/L fusion in the type 6C group. However, the correction rate in both TL/L fused and thoracic non-fused curves was lower compared to the Lenke type 5C group at any time during the study. The results reported by Direito-Santos et al. [42] of 10 patients with Lenke 6C AIS curves undergone anterior selective TL/L fusion with a correction rate of 22.4% of the unfused thoracic curve were also comparable to the previous study. Worsening the unfused thoracic curve in the follow-up period is probably related to the residual growth potential at the time of surgery.[17, 43] Compensatory thoracic curves are relatively flexible and likely to be corrected spontaneously following selective TL/L fusion in skeletally immature patients. However, the development of unfused thoracic curves needs investigating more due to immaturity. Chang et al. also showed no statistically significant difference in the thoracolumbar/lumbar AVT at any time point, which may be the actual reason for similar SRS-22 scores between the two groups. In patients with AIS, the ultimate treatment aimed to correct their appearance and spinal balance while shortening the fusion level, and the selective TL/L fusion is a valuable treatment option for Lenke 6C curves.

Lowest instrumented vertebra selection

One of the main issues in selective TL/L fusion is the selection of the LIV so that more fusion cause better correction with less spine movement. Therefore, the selection of LIV should cause the maximum correction and movement.

Wang et al.[44] proposed two formulae for selection of LIV and anticipation of final correction and balance: final lumbar Apical Vertebra (AV) – Central Sacral Vertical Line (CSVL) distance = 14.1 + 1.2 (preoperative LIV-CSVL distance); final thoracic AV-CSVL distance = 36.2 + 0.5 (preoperative thoracic AV-CSVL distance) + 0.7 (preoperative LIV-CSVL distance). They also considered translation up to 28 mm and tilt up to 25º as general criteria for selecting LIV. For example, the final lumbar AV-CSVL distance of 25 mm can result in less than 9.1 mm of preoperative LIV-CSVL distance. Zhuang et al. [45] defined criteria for LIV selection as follows: 1) the most cephalad vertebrae touched by CSVL, 2) grade one or less rotation in Nash-Moe grading system on the standing AP radiograph, 3) CSVL pass between the two pedicles of LIV on concave bending film, and 4) not at the apex of kyphosis. Based on in King classification, CSVL is defined perpendicular to the crest line.[2] Ilharreborde et al.[46] also showed that in patients with adding-on phenomena (a progression greater than 5º of the LIV frontal tilt), LIV was the vertebra above the Last Touching Vertebra (LTV) in 62.5% of the patients and above the stable vertebra in 87.5%. Therefore, the selection of the LIV may need to take stable vertebra and LTV into consideration.

Sagittal alignment

Few articles evaluated the sagittal plane in selective TL/L fusion despite the coronal plane. A total of 39 patients with Lenke type 5C AIS, who had undergone posterior selective TL/L fusion [47] were evaluated that were divided into two groups based on T5-T12 kyphosis (Lenke's sagittal modifier), as follows: N (between 10 and 40 degrees) and M (less than 10 degrees). Overall; the main TL/L curve, minor T curve, TK (T1-12), lower TK (T5-12), TLK (T10-L2), cervical lordosis (CL), T1 slope, C7 sagittal vertical axis (SVA), and apex of TK were significantly changed in preoperative and after final follow-up. LL, Sacral Slope (SS), Pelvic Tilt (PT), and inflection point were not significantly changed after surgery. Regarding Lenke's sagittal modifier groups, preoperative TK (T1–12), TK (T5– 12), TLK, and CL were significantly different from both groups. There was no significant difference between the two groups after the operation. These results were consistent with those of Okubo et al.'s study, [48] which showed that selective TL/L surgery was more likely to affect Group M than Group N for the sagittal plane. In this regard, Karademir et al.[49] suggested that SF be performed only for Lenke's sagittal modifier N, not for patients with T5-T12 kyphosis more than 40°. On the other hand, LL and spinopelvic parameters change after selective TL/L fusion, [50-52] showing the average fusion length was longer, and the LIV was more distal to influence the lumbosacral alignment.

In 2017 for the first time, Wang et al. [53] evaluated the correlation between posterior selective TL/L fusion and Cervical Sagittal Alignment (CSA) in 30 patients with Lenke type 5C AIS; they concluded that CSA is not directly affected by postoperative lumbar curve correction. However, indirect overcorrection of the TL/L curve led to an increased Thoracic Sagittal Alignment (TSA), which increased the T1 sagittal inclination affecting CSA in patients with Lenke 5C AIS. In addition, the T1-slope was related to the C2-C7 lordosis, proximal-TK, and the global-TK in the preoperative and postoperative periods. Increased TSA tends to develop CL due to the preservation of horizontal vision in some individuals. However, a few patients exhibited a restored CL because of the inherent rigidity of the cervical spine.

Long term outcome

The outcome, patient satisfaction, and complications of long-term follow-up of selective TL/L fusion are considered crucial information. Based on a study by Etemadifar et al. [54] on all patients undergoing SF to evaluate the long-term outcome of SF in AIS, the patients improved significantly after surgery. The ratio of thoracic AVT to thoracolumbar/lumbar AVT also significantly improved. Additionally, Etemadifar et al. noted that none of the patients had a progression of deformity, adding on deformity, coronal decompensation, and repeated surgery. Patient satisfaction analysis also showed that 85.8% and 9.2% of patients were satisfied and unsatisfied, respectively.

Louer et al. [55] distinguished selective thoracic fusion cases from TL/L and evaluated each group separately. The average TL/L coronal curve magnitude was 45º ± 8 º preoperatively and 16 º ± 7 º at the first-erect follow-up (64% correction) with a comparable correction rate at the mid-range and 10-year follow-up time points regarding before surgery (62% and 60%, respectively; P-value > 0.05). The instrumented compensatory MT curve averaged 25 º ± 8 º preoperatively, 20º ± 8º (21% correction) at the first-erect follow-up, and 16 º ± 7 º at the 10-year follow-up (60% correction rate compared to before surgery). A significant improvement in Coronal Balance (CB) was achieved from 3.1 cm preoperatively to 0.9 cm at 10 years follow- up (P-value < 0.001) in patients undergoing selective TL/L fusion. Postoperative TK did not reveal any significant differences compared to preoperative time points, and LL remained normal following fusion, even with an interim lumbar hypolordosis at the first-erect time point.

In the Delfino et al. [56] study, 35 AIS patients undergone selective anterior TL/L fusion were evaluated for at least 12 years. The preoperative TL/L Cobb angle was 49.5º±9 with 79%±13 and 72%±18 correction rates in postoperative and final correction, respectively. The thoracic Cobb angle was 31.4º±14.2 preoperatively, 18.4º±11.9 postoperatively, and 17.8º±10.8 at the final follow-up. Apical vertebral rotation improved from 25.8º±7.8 to 9.2º±5.5 and finally to 8º±5.2 (P-value=0.001). Sagittal parameters (T5-T12=27.2º and L1-S1=56.9º) did not change significantly at each time point; CB improved from 2.4 cm to 1.6 cm postoperatively and 0.8 cm at final follow-up (P-value=0.006) without any revision surgeries or infections. One patient was undergone lumbar pain surgery due to symptomatic lower disc degeneration.

Direito-Santos et al. [42] reviewed selective TL/L fusion via anterior procedure on 65 patients with Lenke Type 5C and 10 with Type 6C with a mean 9-year follow-up. In Lenke type 5C patients, the correction rate of the TL/L fused curve was 85.1%±10.5, which was similar at the final follow-up (P-value>0.05). Regarding the unfused thoracic curve, the correction rate was 59.9%±30.5 postoperatively, which increased to 66.3%±28.9 at the final follow-up (P-value<0.018). CB decreased from 28.9mm±14 to 5.7mm±6.7 (P-value<0.001) with no significant changes in the final follow-up. The TK and LL had no significant differences compared to preoperative values. In the Lenke type 6C group, the mean preoperative TL/L Cobb angle was 58.6º±13.9; the mean postoperative TL/L Cobb angle was 22.6º±14.5 (P-value<0.001) with a correction of 62.5%±20.6, which was similar to the final follow-up (P-value >0.05). The thoracic Cobb angle changed from 39º±7.6 to 30.6º±10.1 (P-value <0.008) with a correction rate of

22.4%±17.5. In the final follow-up, the thoracic Cobb was 29.3º±10.7 with no significant change regarding postoperation. In this group, CB decreased from 20.9mm±14.5 preoperatively to 16.6mm±14.2 (P-value=0.086) in the final follow-up. Asymptomatic last-level non-union was confirmed in 10 patients (15.4%) in the type 5C group and two patients (20%) in the type 6C group. No significant degenerative changes were detected in the final radiographic evaluation.

Moreover, Chen et al. [57] conducted a study on Lenke type 5 AIS with a mean follow-up of 11.26±0.85 years to evaluate posterior selective TL/L fusion. The mean preoperative thoracic and TL/L curves Cobb angles were 24.0±9.0º and 45.4 ± 6.3º, respectively, corrected to 12.2º and 12.4º at the 3-month postoperatively, with correction losses of 2.2º and 1.5º at the 10-year follow-up. They also stated that 20 out of 37 patients in their study showed CIB before surgery. However, most of the patients reached the normal level during the first 3 months after surgery and the entire follow-up period; in addition, the degree of TK and Proximal Junctional Angle (PJA) piecemeal increased over the follow-up period. PJK occurred in one out of 37 (2.7%) and 12 out of 37 (32.4%) patients at three months and 10 years postoperation follow-up, without any significant difference between group M and group N (according to Lenke sagittal modifier), between imbalance group and balance group at three months and ten years post-operation. Therefore, PJK remained a multifactorial problem and a dynamic compensatory mechanism that coordinated to maintain the balance of the human body and minimize energy expenditure during walking or standing.

The adding-on phenomenon and decompensation of the thoracic unfused curve are considered important side effects of SF, causing some spinal surgeons not to use the selective technique. The adding-on phenomenon is characterized by a progressive loss of correction by either vertebral deviation of the lumbar spine or disc angulation below the LIV. Adding-on phenomenon and thoracic curve decompensation were reported up to 36% and 29%, respectively.[6] However, there was no need for revision surgery in most cases, and patients did not complain clinically.[6,45] Consequently, the criteria of puberty, especially menarche in girls, is very important [Figure 1]. Demonstrates the result in selective TL/L fusion, a 14- years old girl before menarche that met all selective TL/L criteria except TL kyphosis more than 20°, and a premenarchal girl, who had gone under selective TL/L fusion. Eight months later, the thoracic curve was decompensated, and her fusion levels were extended. It seems that if the selective TL/L fusion is performed with the exact criteria discussed earlier, the rate of correction loss in the fused TL/L and non-fused thoracic curves is not significant. In most cases, patients do not have any clinical problems, and therefore no revision surgery is necessary.

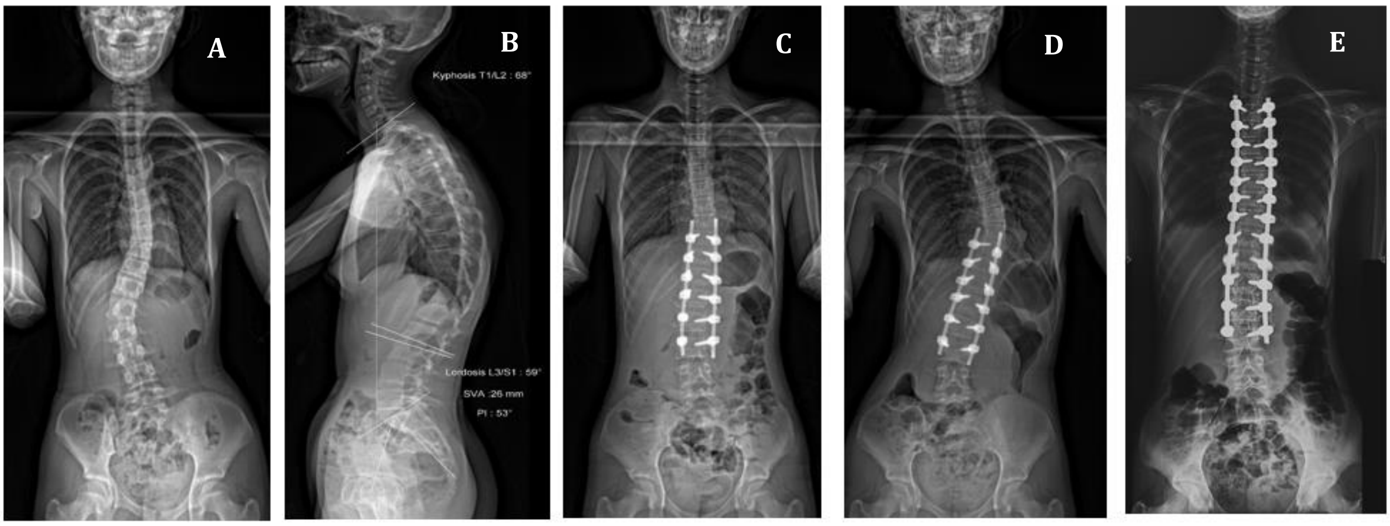

Figure 1. (a) Anteroposterior and (b) lateral spinal EOS of a 14 years old premenarchal girl and TL kyphosis more than 20 °with Lenke type 5C AIS. (c) Early postoperative EOS after selective TL/L fusion. (d) Thoracic curve decompensation eight months later. (e) She underwent extension of proximal fusion levels.

Conclusion

The selection of patients and LIV based on objective criteria led to the results of selective TL/L fusion surgery for anterior or posterior approach will be satisfactory with fewer complications.

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